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FORTY-THIRD PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

Period Ending September 30, 1971

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Institute for Basic Standards
Boulder, Colorado 80302

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◇ **NBS** ◇

U.S. DEPARTMENT OF COMMERCE

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* Continuing effort

1. Cryogenic Properties of Solids

1.1 Thermal Conductivity of Solids

1.1.1 General Comments

The objectives of this program are (1) to measure the thermal conductivities of several standard reference materials, (2) to study Lorenz ratio of several classes of materials, and (3) to study conduction mechanisms in alloys in the temperature range from 4 to 300 K.

Personnel contributing during the reporting period were J. G. Hust, L. L. Sparks, S. Schmidt, and M. Prouhet.

1.1.2 Program Status

During the current period the principal efforts were directed toward the Lorenz ratio compilation and completing the report on AGARD stainless steel standard reference material as well as reports on other materials measured previously.

The compiled Lorenz ratio data have been punched on computer cards, and computer analysis is nearly complete for Cu, Fe, Ni, and commercial alloys of these metals. Preliminary graphs of these data are presented in figures 1.1.1 through 1.1.6. [The numbers in brackets, both in the text and in figure captions, refer to the list of references.] It is seen from these figures that the Lorenz ratios of pure metals are near the Sommerfeld value, $L_o = 2.44 \times 10^{-8} \text{ V}^2/\text{K}^2$, at low temperatures (residual region), falls to lower values at intermediate cryogenic temperatures, and increases again to near L_o at higher temperatures, as expected. Also, as expected, one can see the dependence on impurity concentration at intermediate temperatures. For the alloys, one obtains the expected increase in Lorenz ratio at intermediate temperatures instead of a dip as for the pure metals. This increase in L is evidence of a relatively large lattice conductivity.

Somewhat challenging is the large spread in Lorenz ratios for the given classes of materials at each temperature. This large spread will result in large uncertainties in predicted thermal conductivities based on these curves. Further subdivision of materials may be necessary to achieve a sufficiently small spread to be useful.

The present objective of the Lorenz ratio compilation project is to separate materials into classes based on similar Lorenz ratio curves. From these curves and a knowledge of the electrical resistivity of a new material from that class, it is often possible to predict the thermal conductivity of the new material. The compilation to achieve the above objective has revealed some other interesting possibilities for prediction of thermal conductivities. For example, in several instances data exist in the literature which will allow computation of the specific thermal resistivity resulting from controlled addition of impurity atoms in a given host material. It has been noted that some impurities are much more effective scatterers than others. From a table of specific thermal resistivities, similar to that compiled by Blatt[35] for electrical resistivity, one may be able to accurately predict the electronic thermal conductivity of metals and alloys. Of the huge number of host-impurity element combinations which exist, only a few have been measured. However, there is a good possibility that one can construct such a table from a knowledge of L(T) for pure metals and Blatt's specific electrical resistivities. The measurements which have been published can be used to check the accuracy of such calculations.

Since impurities scatter both electrons and phonons more effectively when in solution than when segregated at grain boundaries, it may be possible to study grain boundary resistivities with the compiled data. The available data will also be useful in

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examining lattice conductivity. Both of these studies will be necessary to accurately predict the total conductivity of high solute concentration alloys. Our present work schedule does not allow a detailed investigation of these potential predictive methods, but preliminary studies can be performed to determine whether or not further research will be productive.

Considerable progress also has been made in reporting past measurements. A report on the AGARD stainless steel standard reference material is nearly completed. The following reports have been completed:

(1) J. G. Hust and L. L. Sparks, Thermal Conductivity Standard Reference Materials from 4 to 300 K: IV AGARD GOLD, NBS Report 9785 (1971).

(2) J. G. Hust and L. L. Sparks, Thermal Conductivity, Electrical Resistivity, and Thermopower of Aerospace Alloys from 4 to 300 K: VI Fe-22Cr-13Ni-5Mn Stainless Steel, NBS Report 9799 (1971).

(3) J. G. Hust and L. L. Sparks, Thermal Conductivity of Electrolytic Iron, SRM 734, from 4 to 300 K, NBS SP 260-31 (1971).

During the next reporting period, the Lorenz ratio compilation will be completed with graphs for each of the common metals and structural alloys. We will continue to study heat conduction mechanisms and potential predictive schemes.
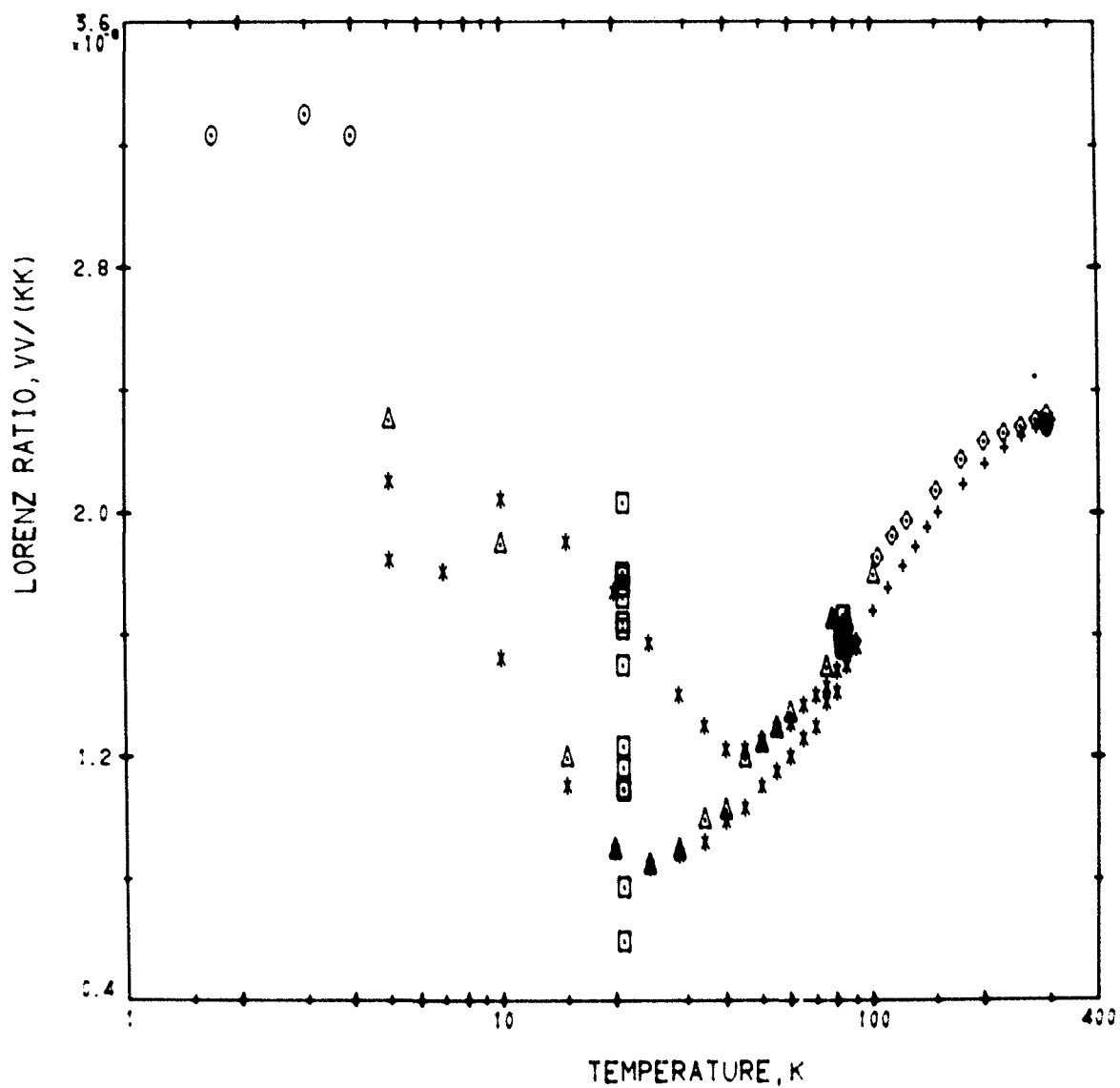
Figure 1.1.1 Lorenz Ratio of Copper

o -[1]; ▲-[2]; □-[3]; ◇-[4]; + -[5]; * -[6]; •-[7]; ●-[8]; △-[9]

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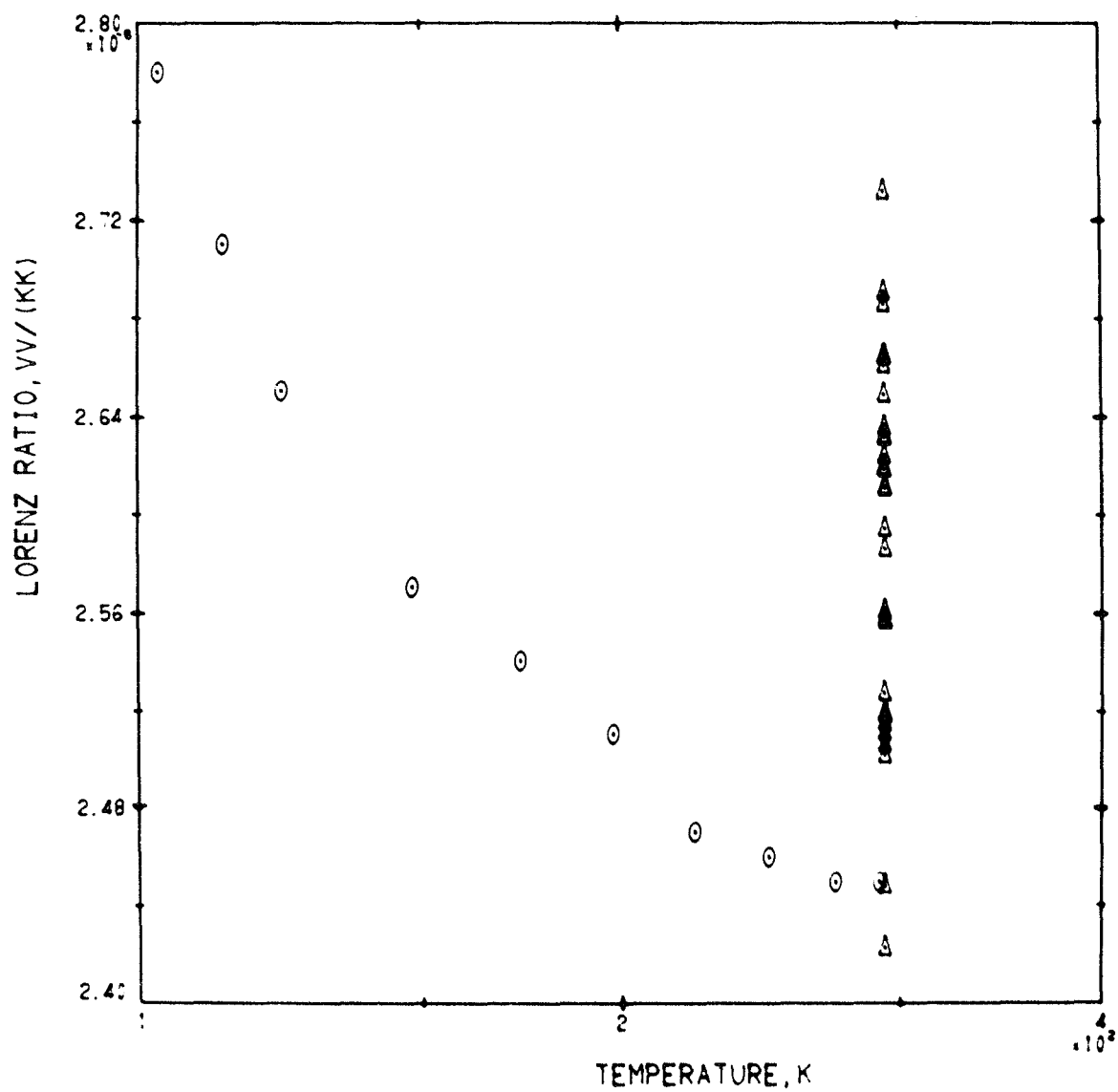
Figure 1.1.2 Lorenz Ratio of Copper Alloys (Brasses)

o -[4]; △ -[8] and [10]

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Figure 1.1.3 Lorenz Ratio of Copper Alloys (Bronzes)

o -[4]

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Figure 1.1.4 Lorenz Ratio of Commercial Nickel Alloys

o-[2]; Δ-[11]; --[12] and [13]; □-[14];∇-[15]

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Figure 1.1.5 Lorenz Ratio of Iron

o -[16]; Δ-[17]; □ -[18]; — -[19] and [20]; ∇-[21];

◇-[22]; + -[23] and [24]; * -[25]; •-[26]

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Figure 1.1.6 Lorenz Ratio of Steels

o-[11]; —-[27], [28], [29], [30], and [31]; Δ-[32] and [33]; □-[34]

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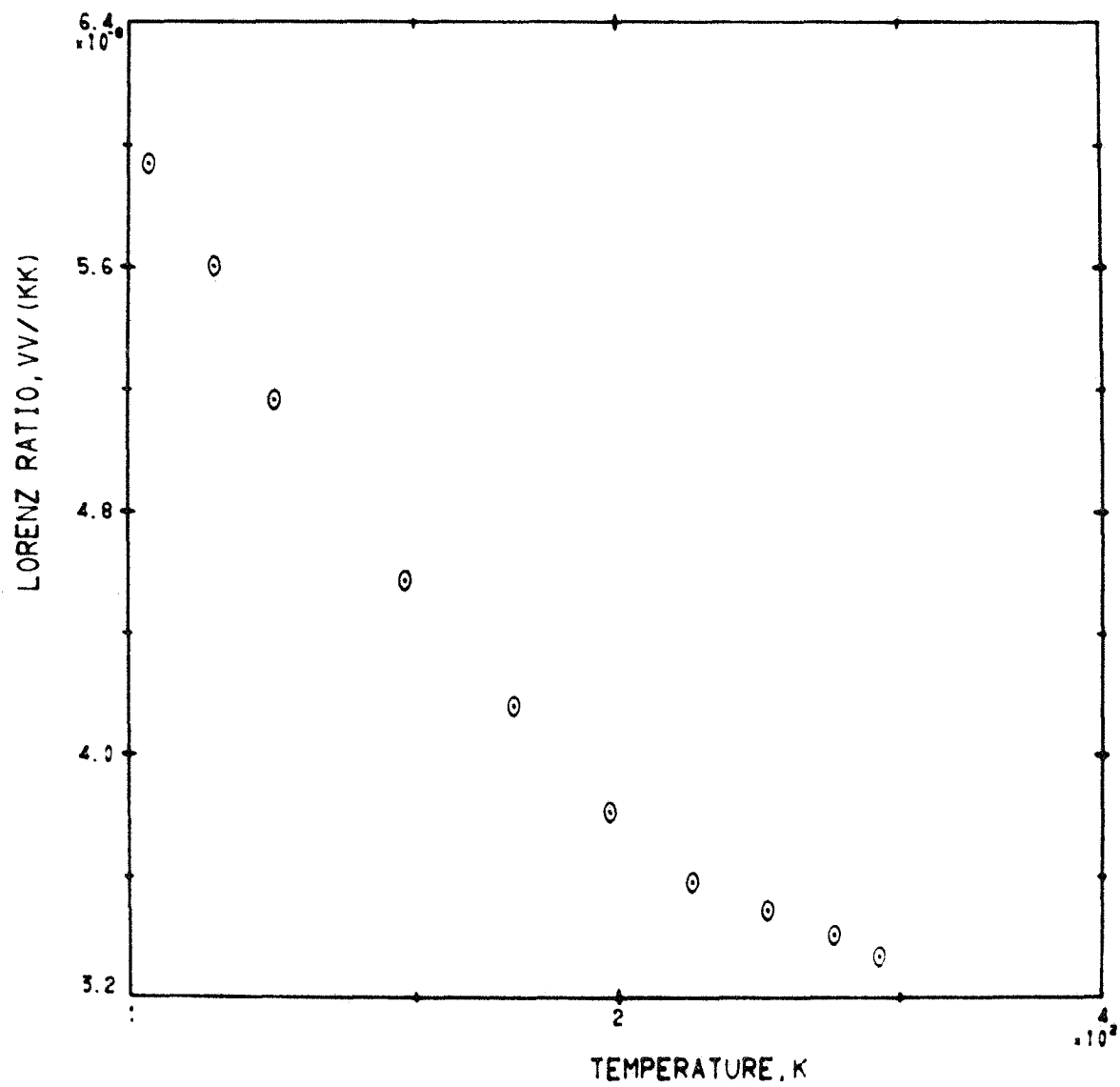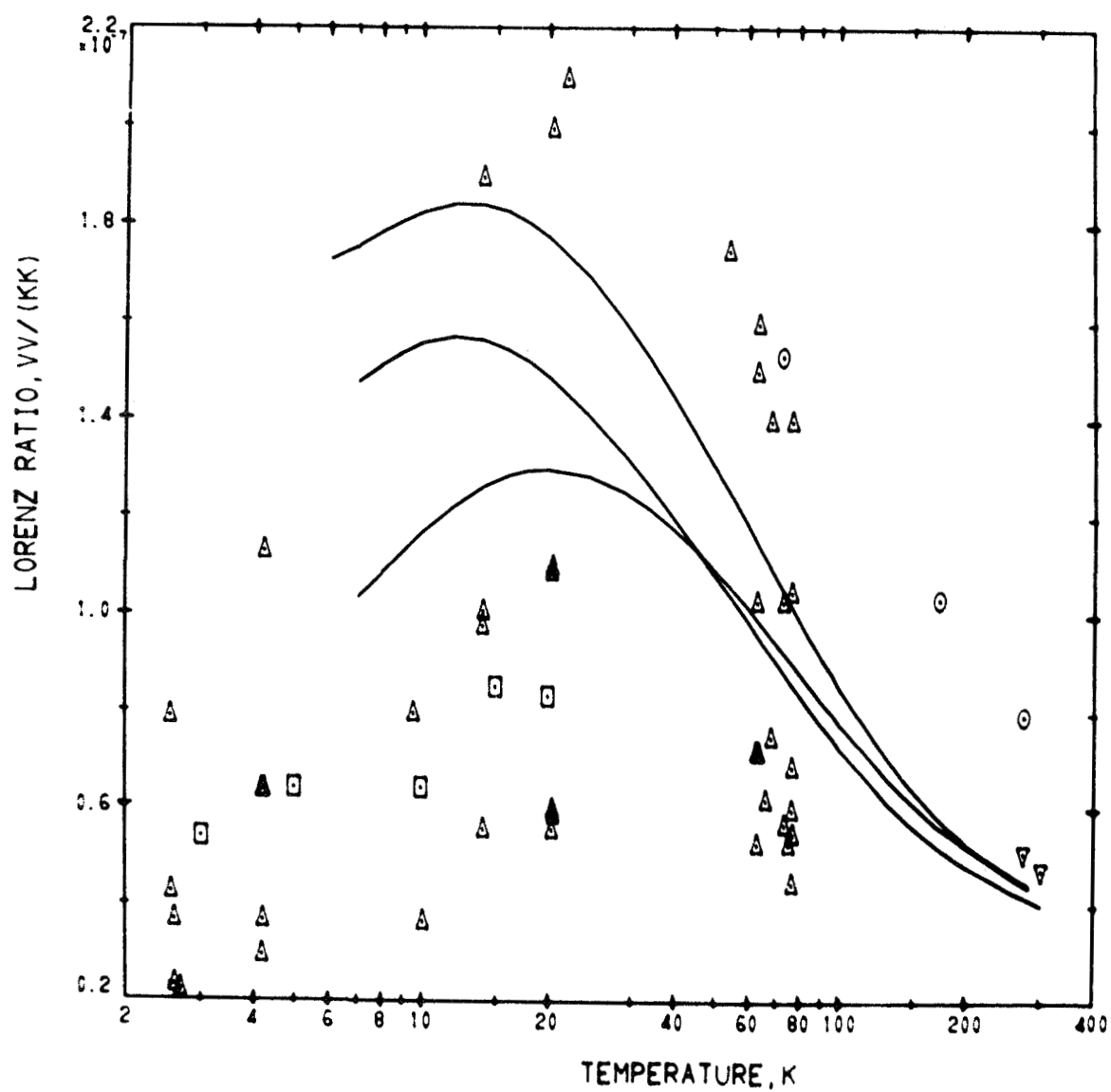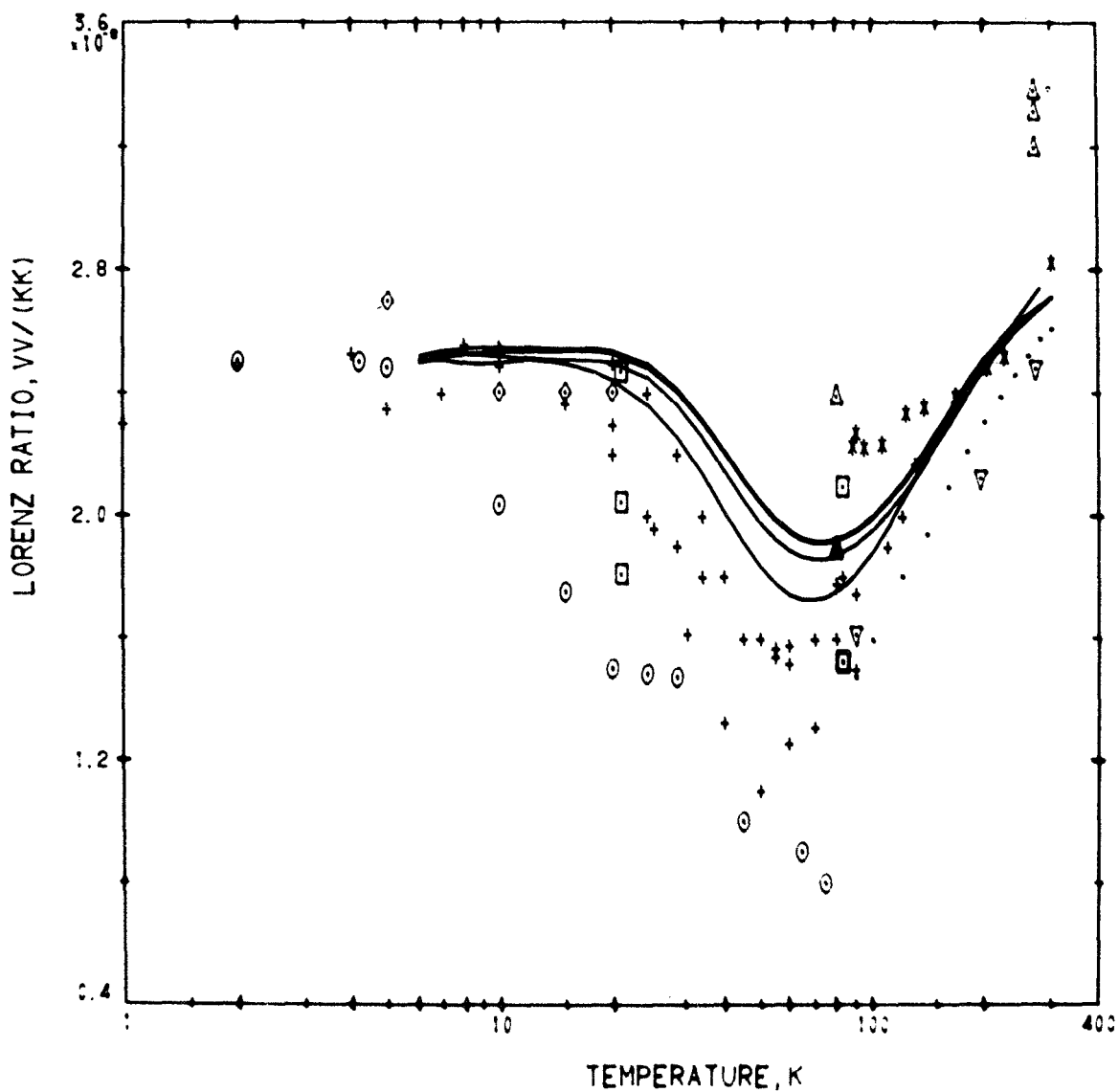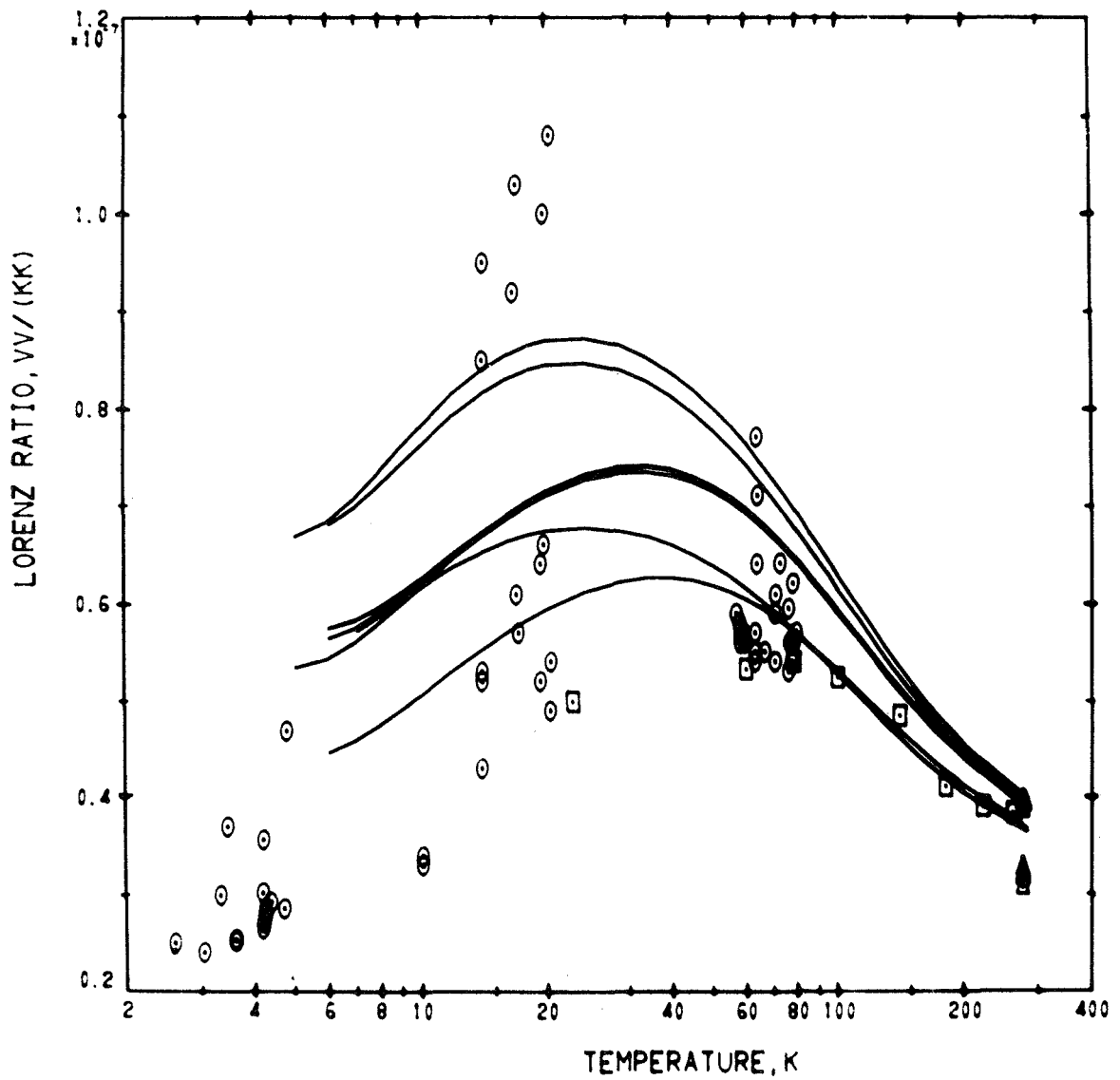
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2. Slush Hydrogen Heat Transfer and Hydrocarbon Suspension

2.0 General Comments

During this reporting period, activities have been concerned with (1) experiments preparing hydrocarbon suspensions in slush hydrogen, and (2) construction of a guarded plate unit for the slush hydrogen heat transfer experimental program. The study of mixing requirements for slush hydrogen systems is completed, and the report will be available shortly. Personnel contributing to the program during this reporting period were C. Sindt, P. McConnell, R. Voth, G. Suenaga, and J. Hord.

2.1 Slush Hydrogen Heat Transfer

The experimental heat transfer unit has been fabricated. It consists of a 2.54-cm-diameter guarded plate which can be oriented facing up or down, or in a vertical configuration. The unit will be installed in the same experimental apparatus that currently is being used for the hydrocarbon suspension work, when that task is completed.

2.2 Hydrocarbon Suspension in Slush Hydrogen

Fourteen tests have been conducted in the hydrocarbon suspension apparatus. The tests have covered both techniques to be investigated in this task (injection of the hydrocarbon into triple-point temperature liquid hydrogen prior to forming slush, and injection of the hydrocarbon into slush hydrogen after formation) and have included the hydrocarbons methane, ethane, and cyclopropane.

2.2.1 Experimental Apparatus

The experimental vessel is a 10-cm-diameter glass dewar with a usable volume of 2 dm^3. This vessel is completely surrounded by a liquid hydrogen bath over which the pressure is reduced by vacuum pumping to maintain the temperature as near triple

point as possible without freezing solid. The hydrogen bath dewar is suspended in liquid nitrogen for thermal radiation protection; all dewars are glass for visual and photographic observation.

Within the experimental dewar is a mixer which is used in the slush preparation process and in the homogeneous mixing of hydrocarbon when preparing the suspension and during sampling of the hydrocarbon content.

A vacuum insulated and heated injection probe is used to introduce hydrocarbon into the liquid or slush hydrogen. It has a 0.33-mm-diameter injection hole, is heated to prevent freezing of hydrocarbon within the probe, and can be lowered to any vertical position in the experimental dewar.

As a means of determining hydrocarbon content of the homogeneously mixed fluid, sampling is accomplished with a micro-sampler that can be lowered into the mixture. The sampler capacity is approximately 1 cm^3. A sample of the mixture is trapped in the device which then is raised above the liquid level, where the sample is completely boiled away into two evacuated gas chambers. One chamber is filled to approximately atmospheric pressure when the hydrogen has vaporized and warmed. This chamber is then closed and the second evacuated chamber is opened. The remaining hydrogen expands into the vacuum — filling the chamber — and the hydro-carbon is subsequently gasified. Since the second chamber is over 300 times larger in volume than the sampler, well over 99 percent of the hydrocarbon expands into it. The two chambers are then mixed and the gas mixture is sampled with a hydrogen flame hydrocarbon analyzer.

Figure 2.2.1 shows the experimental dewar with the mixer, the injection probe, and the micro-sampler lowered into the sample space.

2.2.2 Experimental Procedure

For the experiments in which hydrocarbon is added after slush preparation, the procedure begins with filling the experimental dewar with parahydrogen and cooling the liquid to triple-point temperature. Triple-point temperature is assured by forming a small amount of solid at the liquid-vapor interface. If this solid then settles to the dewar bottom without melting, triple-point temperature is assumed. The liquid volume is determined from a liquid level measurement using a cathetometer. Liquid volume versus liquid level was measured for the experimental dewar in a test using liquid nitrogen. Knowing the volume of triple-point liquid, the mass is determined prior to making slush. Slush is then prepared by the freeze-thaw technique. The volume of the gas removed in slush preparation is measured with a gas meter and the mass removed is then calculated from the density of the gas. The remaining mass can then be calculated and the volume of the slush determined from liquid level. Knowing the volume and mass, the density is calculated and from the density, the solid fraction is determined.

Slush is prepared to the maximum solid fraction that can be attained in a reasonable time without freezing large masses of solid in the ullage space. This solid fraction is between 0.45 and 0.5 in this apparatus.

After preparing slush to the maximum solid fraction, the hydrocarbon is injected at a differential pressure of approximately 380 kN/m^2. The slush is stirred during injection, resulting in the hydrocarbon being distributed throughout the liquid-solid mixture.
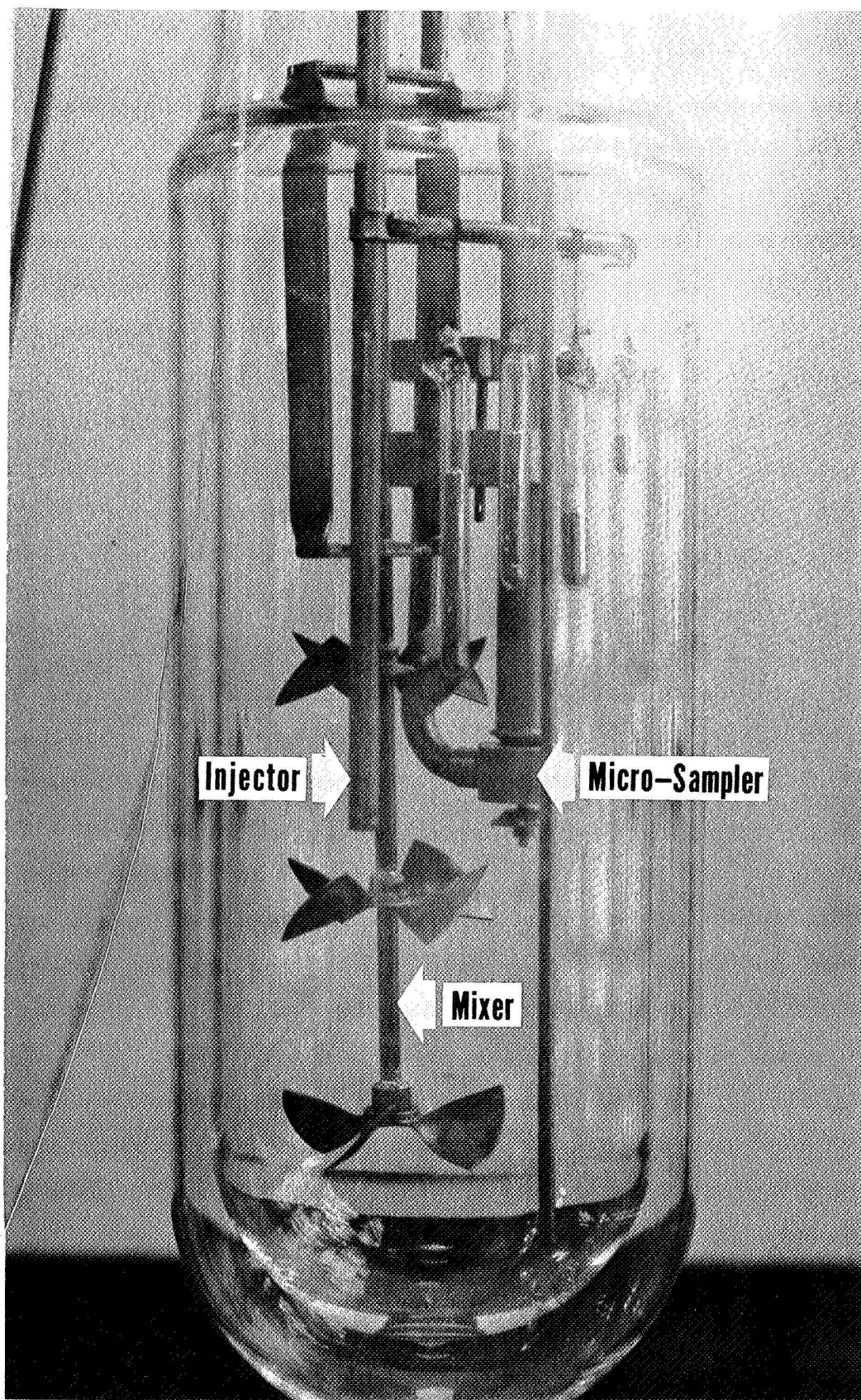
Figure 2.2.1 Experimental Dewar

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The liquid level is then measured again, and from the volume and mass, the solid fraction degradation due to hydrocarbon injection is calculated.

Hydrocarbon content sampling is delayed until the solid hydrogen is melted. The samples taken give a hydrocarbon content based on the total mass of hydrogen in the experimental vessel.

The experimental procedure in which the hydrocarbon is added prior to slush preparation is the same except that the hydrocarbon is added to the triple-point liquid before the slush is formed. Hydrocarbon content sampling is accomplished before slush is formed and after solids have melted, with the appropriate correction made for the loss of hydrogen mass during slush formation.

2.2.2.1 Hydrocarbon Sampling

A technique has been developed that gives fairly consistent results in sampling the liquid-hydrogen, solid-hydrocarbon mixture during vigorous mixing. This technique results in a good measurement of the concentration of hydrocarbon in all of the hydrogen in the experimental vessel. However, sampling of the settled solids has not proven to be repeatable since samples vary as much as 200 percent in hydrocarbon content; the reason for the inconsistency is not known. Because another method can be used to determine hydrocarbon content in settled slush, no more experimental time will be devoted to developing the micro-sampler technique.

The method of determining hydrocarbon content in the settled slush consists of measuring the volume occupied by the settled solids of hydrogen and hydrocarbon and then calculating the concentration based on hydrocarbon concentrations taken in triple-point liquid. This method will provide correct concentration immediately after injection and mixing or after slush preparation and mixing since the

hydrocarbon is then totally dispersed within the volume occupied by the slush.

2.2.3 Experimental Results

Experiments were conducted injecting methane, ethane, and cyclopropane into slush hydrogen. The hydrocarbons injected were 99 percent or higher purity gas.

In the experiments with methane injection, the solid fraction of slush was 0.47 prior to injection. Methane injection reduced the solid fraction to 0.37. This reduction of solid fraction during hydrocarbon injection occurs because the incoming hydrocarbon gas must be cooled, condensed, frozen and further cooled to the triple-point temperature of hydrogen. Refrigeration required is supplied at the expense of melting solid hydrogen. The quantity of solid melted as a result of the methane injection agrees quite well with the predicted value for 4000 parts per million by mass of methane injected.

The resulting slush/hydrocarbon mixture definitely was not gelled, as clear liquid was visible over the settled solids of hydrogen and hydrocarbon. Hydrocarbon particles settled out of the liquid hydrogen (into the slush) almost immediately after the mixing was stopped. These particles were mechanically supported by the hydrogen slush and appeared to be dispersed throughout the settled slush portion of the hydrogen. Evidence to this effect was provided by observation of a settled layer of hydrocarbon which formed on top of the slush as the solid hydrogen melted. Ethane injection into slush hydrogen was very similar to methane injection — the significant difference being that the solid fraction decreased by a larger amount during injection, from 0.47 to 0.29. This is a greater reduction than that predicted by calculation for the 5500 parts per million by mass of ethane injected.

After injection and mixing, the hydrogen was not in a gelled condition; considerable liquid existed over the settled solids.

Injection of cyclopropane into slush hydrogen resulted in more melting of solid hydrogen than with methane or ethane. The solid fraction dropped to 0.15 from injection of 7800 parts per million by mass of cyclopropane. The larger amount of cyclopropane would melt more solid hydrogen; however, the solids melted were more than proportionately greater in quantity than for ethane and methane. Since some of the thermodynamic properties of cyclopropane are not available for calculating the required refrigeration, no comparison between experimental and theoretical melting of solid hydrogen can be made. As with methane and ethane, the resulting mixture was not gelled.

The hydrocarbon that came nearest to gelling the slush was methane. Because aged slush can be higher in solid fraction than freshly prepared slush, it may be possible to gel aged slush. Slush that is 0.6 solid fraction could possibly be gelled; however, to produce a usable quantity of this solid fraction of aged slush in the experimental apparatus would require changing to silvered dewars and some other minor changes to further reduce heat leak. Since injection before slush formation has advantages over injection after slush preparation, the required changes were not made.

Experiments were conducted with hydrocarbon injection prior to slush preparation using methane, ethane, and cyclopropane. The injected methane was mixed with hydrogen gas to get 10 percent hydrocarbon by volume of mixture. After injection, the average of the samples taken for hydrocarbon content was 4400 parts per million by mass, and after preparing slush, it was 4800 parts per million by mass. With slush of 0.42 solid fraction, this hydrocarbon content resulted in a gelled slush. In another experiment with 4000 parts per

million by mass, 0.47 solid fraction was required for gelling. Gelling here refers to the presence of several characteristics of the mix: a) solids occupying the total and same volume as the slush hydrogen, and b) an apparent highly viscous fluid which is observed in the stirring process. No viscometer or penetrating devices were used to compare gel strengths.

Experiments with ethane injection into triple-point liquid prior to slush preparation were made with 3 percent by volume of ethane in hydrogen gas. During the experiments made with ethane, no gel was produced as the maximum solid fraction attained was 0.31 and this was with 7500 parts per million by mass of ethane. Ethane appears to produce the most flocculent solid particle at injection and may, therefore, require the least quantity to gel the slush. More experiments will be conducted with ethane.

The injection of cyclopropane into triple-point liquid hydrogen prior to slush formation was made using 10 percent by volume of cyclopropane in hydrogen gas. With approximately 8500 parts per million by mass in slush of 0.52 solid fraction, a stiff gel was formed. In this particular experiment, significant amounts of solid hydrogen were present in the ullage above the liquid level. This gel point therefore is not accurate for determining the exact solid fraction of slush and content of cyclopropane to form a gel; however, it is evidence that the cyclopropane will gel slush.

2.2.4 Discussion

In the experiments where hydrocarbon was injected into triple-point liquid, note should be made of the decrease in bulk volume of the solid hydrocarbon from the time immediately after injection to 5 hours after injection. Figures 2.2.2 and 2.2.3 show the volume occupied by the settled solids of 6500 parts per million by mass of
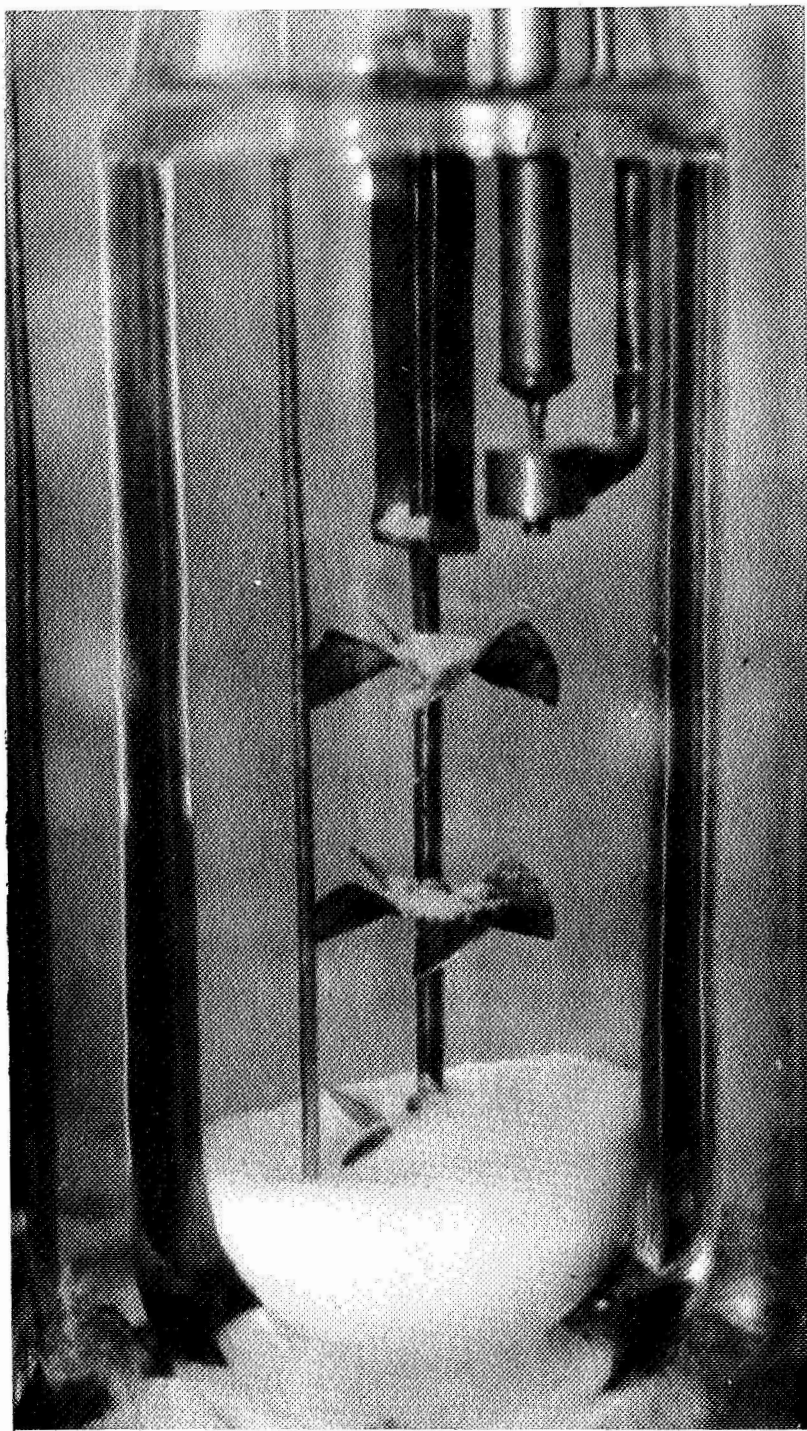
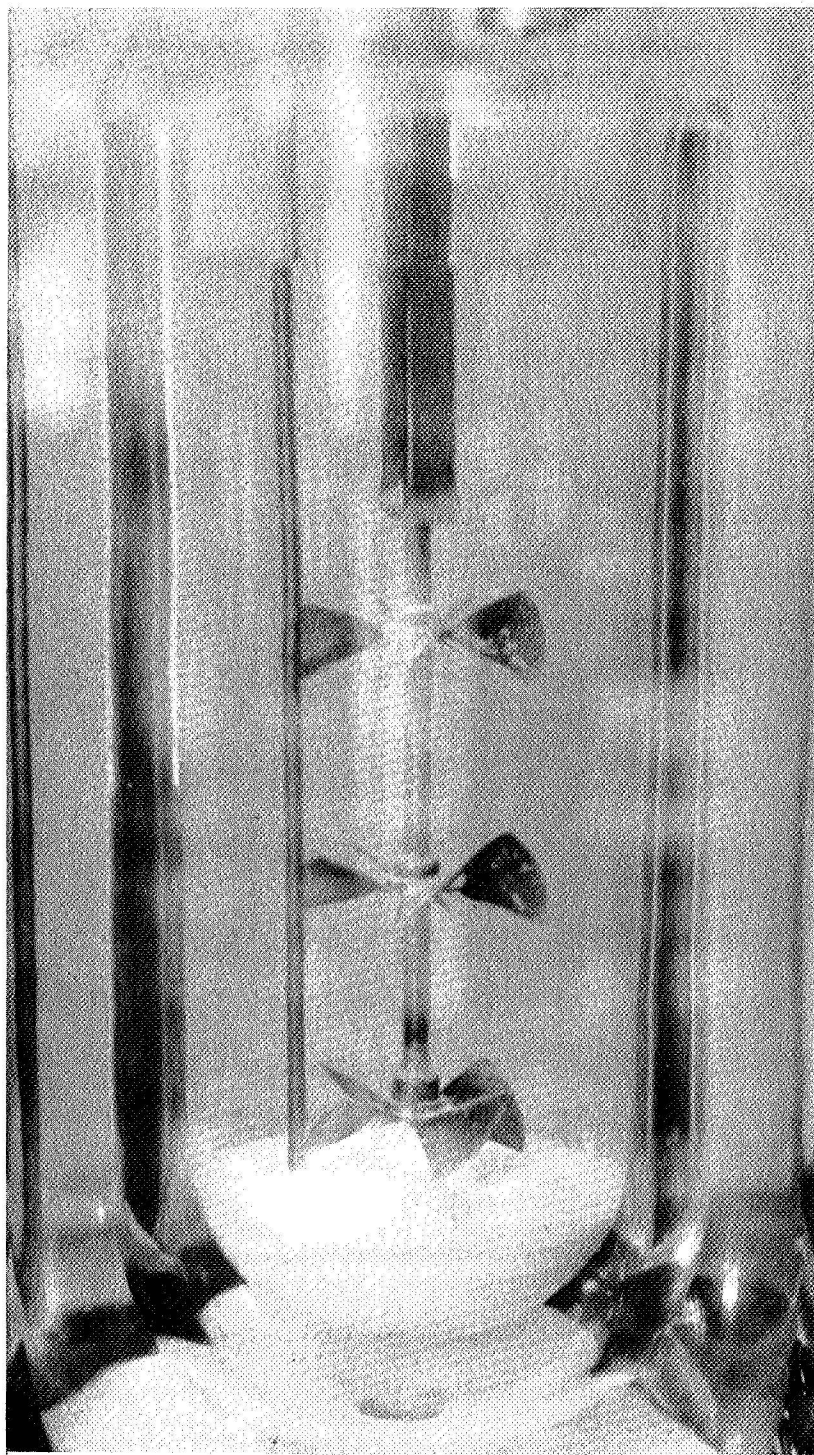Figure 2.2.2 Cyclopropane Immediately After Injection

Figure 2.2.3 Cyclopropane Five Hours After Injection

cyclopropane after injection and 5 hours later after slush has been made and melted. The liquid hydrogen level is near the top of the figure. This volume change was also characteristic of methane and ethane.

In all of the experiments described previously, hydrocarbon was present throughout the settled slush. Even dispersion of hydrocarbon was not verified by sampling because of sampling problems. Because the hydrocarbon appears to be well dispersed and because a layer of hydrocarbon forms on top of the settled slush as solid hydrogen melts, it is possible to verify uniform dispersion. The requirement is simply measurement of the growth of the hydrocarbon layer and the loss of solid hydrogen. Future experiments with ethane will be made for verification of even dispersion.

Since gelling of slush may sometimes be desirable even though the required amount of hydrocarbon is greater than desired, experiments will be conducted with ethane to determine the relationship between solid fraction and hydrocarbon content to form a gel. From all of the experiments performed thus far with ethane, the gelling effect of up to 8000 parts per million of the hydrocarbons used was insignificant. Also, fresh slush of solid fractions greater than 0.45 have some gel characteristics. These characteristics can be described as resistance to sloshing, apparent viscosity increase, and in the extreme case — solid fractions of 0.55 in fresh slush — some ability for the wetted solid to stand or protrude above the apparent liquid surface.

Injection of the hydrocarbon after slush preparation appears impractical at this time as the refrigeration that must be supplied by the melting solid hydrogen degrades the solid fraction at a faster rate than the hydrocarbon gels the resulting triple-point liquid. Also, the method has no apparent advantage over injection prior to slush preparation.

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3. Slush Hydrogen Instrumentation

3.0 General Comments

Contributing to the program during this reporting period was R. S. Collier.

3.1 Thermal Oscillations

The conservation equations are being analyzed using a combination of numerical and variational techniques. The purpose of this analysis is to find the relevant parameters and physical principles which govern the thermal oscillations of the carbon film sensors and other parts of the slush hydrogen system.

It was found that the oscillations described in the last progress report, which depended on pressure gradients, ∇P, near the sensor were much higher in frequency (by a factor of 10^3 - 10^4) than the observed thermal oscillations and also result in temperature variations which are much smaller than observed. These oscillations can be viewed as high frequency, low amplitude sound waves which are generated when the heat pulse is applied to the sensor.

It appears essential to consider the non-linear terms of the conservation equations in order to describe the observed thermal oscillations. The situation is described in part by the following equation which results from combining the conservation equations for density, ρ, and momentum, $\rho \vec{v}$,

$$\frac{\partial^2 \rho}{\partial t^2} - \nabla \cdot \nabla(\pi) = 0 \tag{1}$$

where π is the "momentum flux density tensor". If the viscosity is neglected, then the components of π in rectangular coordinates are given by

$$\pi_{ij} = P\delta_{ij} + \rho v_i v_j \tag{2}$$

where P is the pressure, v_i and v_j are velocity components, and

$$\delta_{ij} = \begin{Bmatrix} 1 \text{ if } i = j \\ 0 \text{ if } i \neq j \end{Bmatrix}.$$

In the linear description of sound waves the velocity terms in (2) are neglected and the approximate equation of state is given by

$$P \approx P_0 + \left(\frac{\partial P}{\partial \rho}\right)_T (\rho - \rho_0)$$

and equation (1) becomes

$$\frac{\partial^2 \rho}{\partial t^2} - c^2 \nabla^2 \rho = 0 \tag{3}$$

which is the sound wave equation, where $c = \sqrt{\left(\frac{\partial P}{\partial \rho}\right)_T}$ is the velocity of sound. It is interesting to note that if the non-linear terms in π_{ij} are included, then equation (1) predicts the existence of shock waves.

On the other hand, the derivatives of pressure gradients do not seem to be important in describing the thermal oscillations of the sensors; if these are neglected, then equation (1) in rectangular coordinates becomes

$$\frac{\partial^2 \rho}{\partial t^2} - \sum_i \sum_j \frac{\partial^2}{\partial x^i \partial x^j} (\rho v_i v_j) = 0. \tag{4}$$

This is an extremely complicated form in general. However, for one dimensional motion, there is considerable simplification which is probably very important for the case of thermal oscillations. For example, in rectilinear motion,

$$\vec{v} = (v(x), \ 0, \ 0),$$

equation (4) becomes

$$\frac{\partial^2 \rho}{\partial t^2} - \frac{\partial^2}{\partial x^2} (\rho v^2) = 0. \tag{5}$$

This appears to be the basic wave equation for thermal oscillations.

Using a variational technique (which will be described in detail in the final report) and the conservation of energy equation along with the approximate equation of state given by

$$\rho = \rho_o + \left(\frac{\partial \rho}{\partial T} \right)_P (T - T_o), \tag{6}$$

(where again the pressure dependence of δ is neglected), the approximate spacial integration of (5) was accomplished and the following equation for the sensor normalized surface temperature, $\Delta T = (T - T_o)/\Delta T_{max}$, was derived:

$$\frac{d_2 \Delta T}{dt^2} + \alpha^2 (\gamma (\Delta T)^2 + (\Delta T)^3) = 0. \tag{7}$$

This equation describes very closely the non-transient time variations of surface temperature which are experimentally observed by the carbon film in slush. The approximate period of oscillation, τ, is given by

$$\tau \approx \frac{\pi}{\alpha} = \frac{\pi^2}{4\sqrt{2}} \ \frac{\rho(2c_v - c_p)a^2}{k \beta (\Delta T_{max})} \tag{8}$$

where k is the thermal conductivity, c_v and c_p are the specific heats at constant volume and pressure, β is the bulk thermal expansion coefficient and $a \approx k\Delta T/q \approx 10^{-3}$ cm is the distance from the surface over which there are significant temperature gradients. For hydrogen near

14 K, $\tau \approx 0.078$ sec which is consistent with experimental observations. A computer drawn graph of the solution to equation (7) is given in figure 3.1.1. The shape of the curve agrees qualitatively with the observed oscillations.

In deriving equation (7), a consistency condition was found which says that $\partial v / \partial x$ is singular whenever $v = 0$. This implies the existence of discontinuities or "shock waves" in the thermodynamic quantities such as entropy and internal energy and invites the speculation that the thermal oscillation is a type of resonant shock wave. This point deserves further consideration.

The problem of controlling or damping the oscillations seems to be closely tied to the separability of the velocity v. That is, the oscillations are enhanced if $v \approx XT$ where X is a function of the space coordinate alone and T is a function of the time coordinate alone. The separability can probably be destroyed by exciting more components of the tensor π_{ij}. Physically this could be accomplished in a number of different ways; for example it probably would be sufficient to wrap the sensor with a thin layer of something resembling coarse steel wool. The details of this analysis will be given in the final report.

The next step is to apply equation (5) (or its equivalent in cylindrical coordinates) to the problem of pressure taps or transfer tubes. Unlike the case of the sensor, the pressure tap consists of a column of gas which has a natural period of compressional vibration. It could be that these natural pressure oscillation modes are excited by thermal oscillations at the cold end of the gas column, since the thermal oscillations are non-linear and thus have a broad frequency spectrum. If this is true, then the oscillations could be damped or

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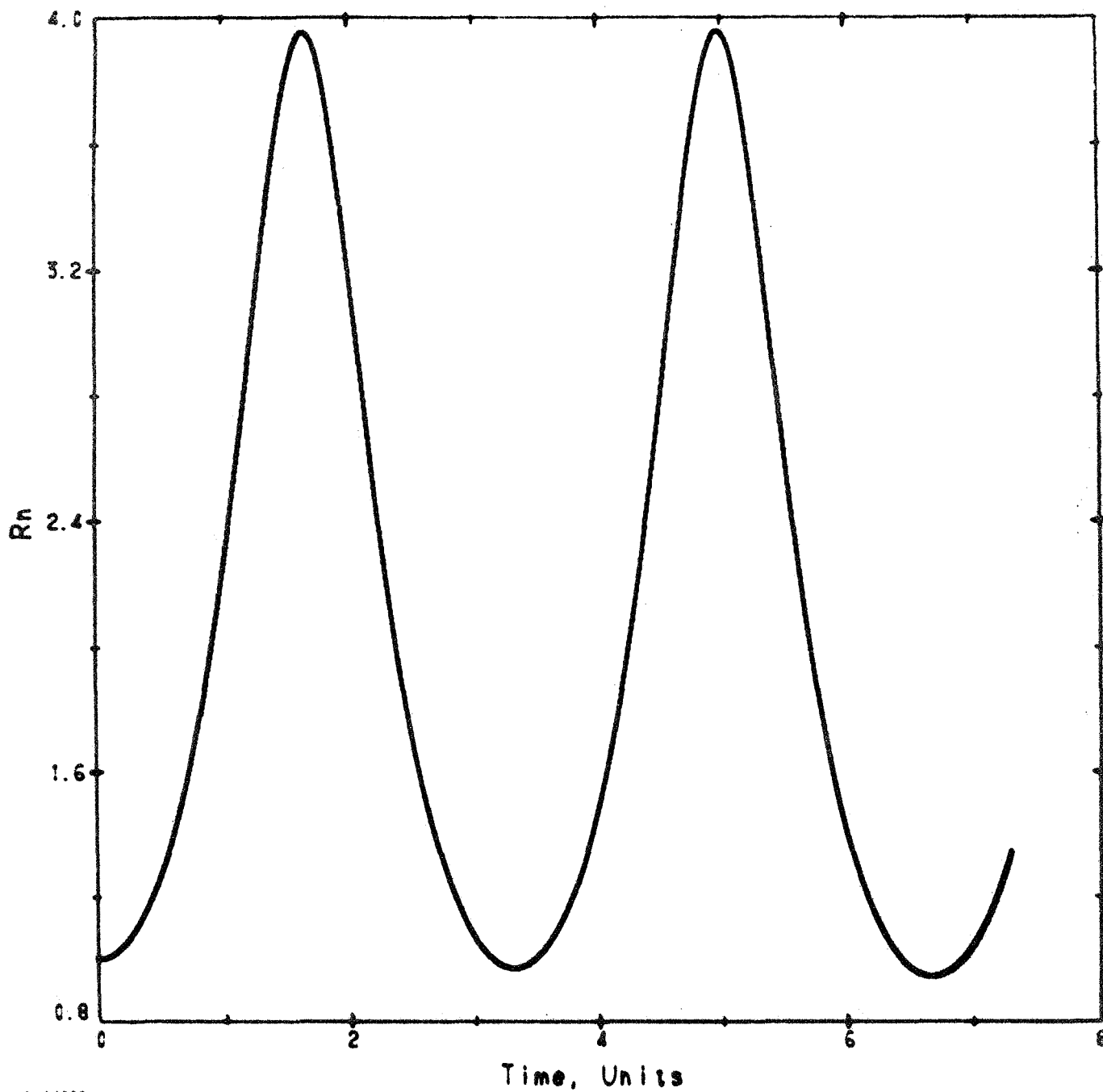
Figure 3.1.1 Thermal Oscillations

controlled as described above) — i. e., by changing the geometry or surface conditions at the cold end of the tap such that the thermal expansion from a temperature rise would induce a turbulent type of motion.

4. Consultation and Advisory Services

4.0 General Comments

Contributing personnel were H. M. Roder and A. F. Schmidt.

4.1 NERVA Program

During the reporting period discussions were held with M. Klein and H. Woolley (NBS-Washington) on error estimates for ideal gas functions, real gas contributions, and dissociation of hydrogen — all at high temperatures. We also discussed differences in source errors for equilibrium vs. para hydrogen with D. Buden (Aerojet). These differences will be illustrated in the forthcoming revised report on the TAB code.

At the present time, there is considerable interest in the properties of hydrogen; several NBS activities related to this topic are listed here for general information. R. McCarty is preparing for NASA-MSC (Smithson) a technical note on hydrogen for the range from the triple point to 600°R and pressures to 5000 psia. The tables of values will include variables such as viscosity, thermal conductivity, dielectric constant, Prandtl number, and several heat transfer parameters. This technical note will be very similar to the recent one on oxygen (NBS Tech. Note 384) and should go a long way toward removing property differences for temperatures just below and just above 100 K, which is the transition temperature between NBS measurements and those of Michels at higher temperatures.

L. Weber is extrapolating hydrogen properties to 10,000 psia for NASA-Hq. (Compitello) for the same range of temperatures. Our plan is to combine both interpolated and extrapolated properties data in one publication. The extrapolation, especially at the lower temperatures and higher densities, is sufficiently uncertain

to require additional experimental measurements. Data in this T-ρ region is needed for pump design. New PVT measurements have been proposed to NASA-Hq. by D. Diller.

For a variety of applications it appears that one single, explicit equation of state which returns values with reasonable speed is essential. Such an equation will be intermediate in both speed and accuracy between the very best values on the one hand and the computational speed of TAB code on the other hand. R. McCarty is presently trying to define this problem for NASA-MSC (Scott). A second part of the problem is to develop a scheme which would return temperature from an input of pressure and density. McCarty's approach, a BWR type equation, may be quite similar to that taken by NASA-LeRC (Hendricks) in the properties program GASP, which, however, at present does not include hydrogen. In this connection NASA is proposing a meeting of the various NASA center representatives at NBS-Boulder in mid-November. One primary purpose of the meeting is to exchange information about each center's requirements for thermodynamic and transport properties data on cryogenic fluids. Finally, a review of the properties of solid hydrogen is contemplated by J. Hord for NASA-Hq. (SNSO).

The electrical resistivity 'round-robin' measurements have been completed by all of the participants, NBS, WANL, ORNL, and BMI. These data were adjusted to a common temperature of 20°C and intercompared. Variances were computed for each specimen and each material. From these data, material variability and interlaboratory reproducibility were estimated. The results showed that electrical resistivity measurements are generally reliable to better than 1%. A report on this work has been provided SNSO-C; copies were subsequently sent to the participants with cover letters from the sponsor.

On July 20, J. P. Layton (Princeton Univ.) visited the NBS Cryogenics Division for an informal briefing on our hydrogen properties programs and related properties information; the application here is to advanced nuclear propulsion systems and concepts.

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